The Patent Office

PCT/GB 2004 / 0 0 1 3 6 4

INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

REC'D 28 MAY 2004

WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 21 April 2004

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
SW
27 MAR 2003
RECEIVED BY FAX

The Patent Office

27MAR03 E795743-1 D00239
P01/7700 0.00-0307077.8

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office
Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference	MK/JMP/P12383GB	
2. Patent application number *(The Patent Office will fill in this part)*	0307077.8	27 MAR 2003
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	University of Strathclyde McCance Building 16 Richmond Street Glasgow G1 1XQ	
Patents ADP number *(if you know it)*		798496001
If the applicant is a corporate body, give the country/state of its incorporation		
4. Title of the invention	A STEREOSCOPIC DISPLAY	
5. Name of your agent *(if you have one)*	Cruikshank & Fairweather	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	19 Royal Exchange Square Glasgow G1 3AE	
Patents ADP number *(if you know it)*	574002	

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	30
Claim(s)	5
Abstract	-
Drawing(s)	7

5

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Cruikshank + Fairweather Date 27 March 2003

CRUIKSHANK & FARIWEATHER

12. Name and daytime telephone number of person to contact in the United Kingdom — Dr Maureen Kinsler 0141 221 5767

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

A Stereoscopic Display

The present invention relates to a stereoscopic display and, in particular, an auto-stereoscopic desktop display incorporating a concave mirror.

Stereoscopic systems attempt to simulate natural stereoscopic vision in order to provide more life-like images. In stereoscopic vision, each eye presents the brain with a two dimensional image of an object or scene from slightly different viewpoints. These images are combined into a single three-dimensional image. In order to simulate stereoscopic vision, auto-stereoscopic systems must be arranged so that a two-dimensional image of the image source is presented separately to each eye. Each image must be from the viewpoint of the corresponding eye, so that two images are provided one for the left eye and one for the right eye of the viewer.

Most existing auto-stereoscopic systems require the user to wear some form of special glasses. In one example, shuttered glasses are used. In this case, alternate left and right images are rapidly displayed on a viewing screen and synchronously the right and left lenses of the viewer glasses are made opaque. Thus, the viewer is presented with the left image to the left eye and a right image to the right eye. In another system, a polarising screen is placed in front of a display screen and again left and right images are rapidly alternated on the display. In this

case, the orientation of the polarising filter screen is alternated, for example, orthogonally in such a manner that one orientation exists while the left image is displayed and the other when the right image is displayed. The user wears passive glasses, each lens of the glasses comprising a polarising filter one of which is orthogonally rotated relative to the other. Thus, when configured properly, again the user is presented with a left image to the left eye and a right image to the right eye.

A disadvantage of these known systems is that the viewer has to wear glasses. A further disadvantage is that they require alternating left and right images to be displayed. This effectively halves the perceived frame rate or image refresh rate and can consequently produce a faint flicker to the user, which can result in viewing discomfort. Whilst this problem can be overcome by running the display monitors at double the frame rate normally used, for example at 120Hz, thereby to provide 60Hz per eye, it is not ideal. A yet further disadvantage is that the glasses effectively act as a filter to reduce the amount of light reaching the eyes from the display. This means that both light and colour loss is experienced. Furthermore, the inherent inefficiency of the filters leads to image ghosting, where some of the image meant for the left eye can reach the right eye and vice versa. When the display is used for a prolonged period of time, this can

lead to visual discomfort.

In order to overcome the problems associated with systems that rely on the use of glasses, various other stereoscopic arrangements have been proposed. For example, in another known display a lenticular screen is used. In this case the need for glasses is avoided because the screen breaks up the original image into a number of left and right elements. A display of this type is described in GB 2,185,825 A. A disadvantage of this is, however, that the actual horizontal image resolution is reduced in proportion to the reciprocal of the number of views presented.

Another stereoscopic system that avoids the need for the user to wear glasses is described in US 3,447,854. This discloses a three-dimensional viewer in which a pair of projectors direct converging left and right image beams along a co-planar axis onto a beam splitter and from there towards a concave mirror. The concave mirror acts as a directional screen and defines two exit pupils at a viewing position, so that the right and left images can be simultaneously viewed. However, whilst the image in this system can be viewed without glasses, it suffers from distortion problems, and in particular key-stoning effects.

US 4,799,763 describes another stereoscopic display that avoids the need for the user to wear glasses. As with the system of US 3,447,854, this too includes a concave

mirror. In this case, however, the concave mirror is used to create a real image projection of two display sources, one for each eye, such that the final image resides at the radius of curvature of the mirror. These images can be viewed by a viewer located at a distance from the screen that is the same as the radius of curvature of the concave mirror. This means that the image is in fact viewed at an overall distance from the concave mirror of about twice its radius of curvature of the concave mirror. A disadvantage of this is that the viewing area available to the user is relatively small. Another problem is that because the concave mirror is the image-forming element, this means that the quality of the concave mirror surface has a significant impact on the overall image quality. In practice, to maximise the viewing area and allow a reasonable degree of head movement, this means that the concave mirror has to be relatively large.

As well as the limitations described above, another problem with many known displays is that the viewing field is relatively limited. To overcome this problem, WO 98/43126 describes a stereoscopic system in which the image projection system can be moved in response to movement of a viewer. More specifically, WO 98/43126 discloses a display generator for generating two images that together represent a stereoscopic image, and a tracking mechanism for tracking movement of a viewer's head. The tracking mechanism is

connected to a controller, which is able to control movement of the display generator. In the event that the viewer's head moves, this is detected by the tracking mechanism, which sends a signal to the controller. The controller then causes the display generator to move so that the image presented on the concave screen moves with the viewer. Whilst this arrangement allows the viewer a reasonable degree of freedom and avoids the need for glasses, it suffers from various disadvantages. Most notably, in order to ensure that the viewer can always see a good image, the image generator has to be moved. A disadvantage of this is that a relatively large space envelope is needed to accommodate this.

An object of the present invention is to provide an improved stereoscopic display, and in particular to provide such a display that avoids the need to wear glasses, whilst providing an improved viewing experience for the user.

According to a first aspect of the invention, there is provided a stereoscopic system comprising an optical element, preferably a concave mirror, that acts as a directional screen and generates a system exit pupil, and a projection system having a focusing element for focusing both of a first image and a second image towards the directional screen.

By using a single focusing element, preferably a single lens, to focus both of the first and second images

onto the screen, image quality can be dramatically improved. Further improvements in quality can be gained by ensuring that the optical axis of the focusing element is aligned with that of the optical element that defines the directional screen, thereby to provide an on-axis system. Because of this, key-stoning effects can be minimised and so image quality can be improved.

A plurality of focusing elements may be used, each being provided for focusing both of the first and second images towards the concave mirror. The plurality of focusing elements may be stacked along a single optical axis.

Preferably, a beam splitter is located on an optical path between the optical element, for example the concave mirror, and the projection system for directing light from the projection system towards that element.

The first and second images may be provided in different planes. The first and second images may be provided in planes that are symmetrically placed relative to an axis. The first and second images may be provided in substantially parallel planes. Alternatively, first and second images may be provided in substantially perpendicular planes.

According to another aspect of the invention, there is provided a stereoscopic system comprising an optical element, preferably a concave mirror, that acts as a

directional screen and generates a system exit pupil, and first and second focusing means for focusing a first image and a second image respectively onto a desired viewing plane, the first image being positioned so that its centre is offset from an optical axis of the first focusing means and the second image being positioned so that its geometric centre is offset from an optical axis of the second focusing means.

Preferably, each of the first and second images is offset by an amount so that each of the first and second image beams converge towards a geometric axis of the first and second focusing elements. Preferably, the geometric axis of the first and second focusing elements is aligned with the optical axis of the optical element, so that the first and second images eventually converge on the optical axis of the concave mirror. By offsetting the first and second images relative to the first and second focussing means, so that each of the first and second image beams converge on the optical axis of the optical element image distortion effects, such as keystoning, can be reduced.

The first and second focusing means may be adapted to focus the first and second images in a viewing plane that is on or in front of or behind the optical element.

The first and second images may be provided by first and second image sources respectively. The first and second image sources may be provided in different planes.

The first and second image sources may be symmetrically positioned. The first and second images may be provided in substantially parallel planes. Alternatively, the first and second images may be provided in substantially perpendicular planes. One or more reflecting surfaces may be provided for reflecting the first and/or second images towards the focusing means.

The first image source may be provided in a plane that is parallel to the optical axis of the first focusing means. In this case, the projection system may further comprise a reflector, such as a flat mirror, positioned so as to reflect light from the first image source into the first focusing means. The second image source may also be provided in a plane that is substantially parallel to the optical axis of the focusing means. In this case, the projection system may further comprise a second reflector, such as a flat mirror, positioned, so as to reflect light from the second image source into the second focusing means.

According to another aspect of the invention, there is provided a stereoscopic system comprising a movable optical element, preferably a concave mirror, that acts as a directional screen and generates a system exit pupil; a projection system for projecting first and second images towards the optical element, the first and second images being provided from first and second image sources; a

tracking system for tracking movement of a viewer, and a drive for causing movement of the optical element in response to movement detected by the tracking system.

By moving the optical element in response to signals from the tracking mechanism, the position of the element can follow that of the viewer, so that an optimum view of the images can be maintained. This simple solution avoids the need for special glasses, without compromising the projection system that provides the images, and whilst providing an apparently larger viewing window for the user.

The projection system may include first and second image mounts or supports for carrying first and second images, the first and second mounts or supports being such that the first and second images are located in different physical planes.

The projection system may include focusing means for focusing first and second image beams towards the optical element. The optical power of the focussing means may be selected so as to project the first and second images onto or in front of or behind the screen defined by the optical element. The display may be provided with a plurality of interchangeable focusing means of different optical powers, so that the location of the image can be varied merely by using a different one of the interchangeable focusing means. Alternatively or additionally, the focusing means may be movable so that the image plane location can be

varied, thereby to provide a zoom facility.

The focusing means may comprise first and second focusing elements, for example first and second lenses, the first element being located so as to project the first image towards the optical element and the second element being located so as to project the second image towards the optical element. Alternatively, the focusing means may comprise a single focusing element for focusing both of the first and second images onto the screen. The single focusing element may be a lens. One or more reflecting surfaces may be provided for reflecting the first and/or second images onto the focusing means.

The first and second images are provided by first and second images sources. The first and second image sources may be provided in different planes. The first image source may be provided in a plane that is parallel to the optical axis of the first lens. The projection system may further comprise a reflector, such as a flat mirror, positioned so as to reflect light from the first image source into the first lens.

Preferably, a beam splitter is located on an optical path between the concave mirror and the projection system for directing light from the projection system towards the concave mirror.

According to yet another aspect of the invention, there is provided a stereoscopic display comprising an

optical element, preferably a concave mirror, that provides a viewing surface, and a projection system including one or more reflecting surfaces for directing first and second images onto focusing means for focusing the first and second images towards a desired viewing plane. By using mirrors to direct the images onto the focusing means, the display can be made more compact than would otherwise be the case, without compromising image quality.

Various aspects of the invention will now be described by way of example only and with reference to the accompanying drawings, of which:

Figure 1 is a schematic diagram of a first auto-stereoscopic system;

Figures 2(a) and (b) are schematic views of two image source and lens systems for use in the arrangement of Figure 1;

Figure 3 is a diagrammatic representation of another image source and lens system for use in the auto-stereoscopic system of Figure 1;

Figure 4 is a diagrammatic representation of yet another image source and lens system for use in the auto-stereoscopic system of Figure 1;

Figure 5 is a diagrammatic representation of still another image source and mirror system for use in the auto-stereoscopic system of Figure 1;

Figure 6 is a diagrammatic representation of a yet

further image source and mirror system for use in the auto-stereoscopic system of Figure 1;

Figure 7(a) is a diagrammatic representation of yet still another image source and lens system for use in the auto-stereoscopic system of Figure 1, and Figure 7(b) is a representation of an alternative lens arrangement for use in the system of Figure 7(a);

Figures 8(a) and (b) are diagrammatic representations of another auto-stereoscopic system;

Figure 9 is a diagrammatic representation of yet another auto-stereoscopic system, and

Figure 10 is a diagrammatic representation of a modified version of the display of Figure 1.

Figure 1 shows an auto-stereoscopic system 10 that includes four basic sub-systems: a concave mirror 12 that acts as a directional screen; a beam splitter 14; a head-tracking device 16 and an image projection sub-system 18 for projecting images onto the concave mirror. Each of the mirror 12, the beam splitter 14 and the image projection system 18 is included in a housing 20. The concave mirror 12 is used as a directional screen and to produce an exit pupil that is formed as a real image of the projection lens assembly 18. The observer looks through this exit pupil to see the image in three dimensions, without the use of glasses.

The concave mirror 12 is located towards the rear of

the housing 20, with the beam splitter 14 positioned in front of it. The beam splitter 14 is adapted so that in use at least some of the light transmitted from the image projection sub-system 18 is reflected from its surface and onto the concave surface of the mirror 12. The transmission/reflection properties of the beam splitter allow at least some of the light reflected from the concave surface 12 to be transmitted through the beam splitter so that images can be viewed by the viewer, who in practice is located on the opposing side of the beam splitter from the mirror 12. As will be appreciated, varying the transmission/ reflection properties of the beam splitter determines the brightness of the images that reach the user's eyes. Ideally, the beam splitter should have a transmission/reflection ratio of 50:50. A pellicle beam splitter may be used.

Light is directed towards the beam splitter by the image projection sub-system 18. This may have single or multiple lenses. A specific example of a multiple lens system is shown in Figure 2(a). This has two identical lenses 22 and 24, one of these lenses 22 being positioned above a right hand image source 26 and the other 24 being positioned above a left hand image source 28. As shown, the lenses 22 and 24 lie in the same plane, although this may be changed by for example tilting the lenses as and when desired. The lenses 22 and 24 are spaced apart by an

amount that corresponds to the average inter-ocular spacing of about 63mm, so that the images projected onto the concave mirror 12 are optically at the correct position to enter the left and right eye of the viewer, that is separated by an amount of the order of 63mm.

The source images 26 and 28 could be provided side by side on a single display or provided on two separate displays. In either case, the first image 26 is positioned so that its centre is offset from an optical axis of the first lens 22. Likewise, the second image 28 is positioned so that its centre is offset from an optical axis of the second lens. The projection lens assembly 18 is itself positioned so that the geometric axis 29, that is the mid-point, of the first and second lenses is aligned with the optical axis of the concave mirror 12. Because of this, the first and second image beams eventually converge on the optical axis 31 of the concave mirror 12. By arranging the projection lens system 18 and concave mirror 12 in this way, distortion effects can be reduced.

As an alternative example, Figure 2(b) shows a single lens projection system, which has a single lens 25 positioned above and extending over each of the right and left hand image sources 26 and 28 respectively. The single lens 25 is adapted to focus light from each of the image sources to produce images that are spaced apart by an amount that corresponds to the average inter-ocular spacing

of about 63mm. As for the arrangement of Figure 2(a), the source images 26 and 28 could be provided side by side on a single display or provided on two separate displays. The projection system of Figure 2(b) is positioned so that the optical axis 27 of the projection lens 25 is aligned with the optical axis 31 of the concave mirror 12.

When the projection systems 18 of Figures 2 (a) and (b) are positioned in the display of Figure 1 as described above, the projection part of the display is essentially on-axis. This is because the geometric axis 29 of the system of Figure 2(a) and the optical axis 27 of the system of Figure 2(b) are substantially aligned with the optical axis 31 of the concave mirror 12. This is advantageous, because the effects of key-stoning can be reduced, and so image quality is improved. Since the viewing position is ideally along the optical axis 31 of the mirror 12, this means that the viewing position for the configuration of Figure 1 is also on-axis. It should be noted, however, that were the concave mirror 12 of Figure 1 to be moved from the position shown, this would not always be the case. This will be discussed in more detail later.

The location of each lens of the image projection sub-system 18 determines the position of the image that is formed. In a preferred example, the concave mirror 12 is located substantially at the image plane of each lens. In this case, the image is formed on the plane of the concave

mirror 12. Alternatively, the lenses could be positioned relative to the concave mirror so that the image is formed in front of or behind it.

The concave mirror 12 is mounted on a kinematic support that has a primary support frame 30 that allows it to be rotated and a secondary support frame 32 that allows it to be tilted. Connected to the kinematic support is a drive system. This drive system includes, but is not restricted to, servo-motors. One of these motors 34 is connected via a transmission system to the axes of the primary support frame and the other 36 is connected to the axes of the secondary support frame. These motors 34 and 36 are operable to steer the mirror 12 in two axes, i.e. pan and tilt, about its geometric centre. Connected to the motors is a control system 40 that is operable to send control commands to cause activation of the motors, and thereby movement of the mirror 12.

Connected to the control system 40 for the kinematic drive system is a tracking device 16 that is operable to monitor the position of a viewer's head and feed back signals indicative of this movement to the control system 40. The head tracking may be implemented in various ways. For example, a reflective target may be provided on the system user, which target would then be tracked by an infrared transmitter- receiver system. Alternatively, a camera system coupled with image analysis software could

track the position of a user's eye. In practice, the latter is preferred because it does not require the user to wear an artificial target. The tracking device of Figure 1 is shown mounted on a front portion of the housing 20. It will be appreciated, however, that it could be located anywhere, provided there is a clear line of sight to the user.

Tracking is implemented using the control system 40. The position of, for example, the user's eyes is acquired by the head tracker 16. This position data is fed back from the tracker to the control system 40 and used as an input to a simple computer algorithm in the control system 40 that produces output information to drive the servo-motors 34 and 36, thereby to ensure that an optimum view of the image is presented to the user as he or she moves around in space. Hence, in the event that the viewer moves his head to the left, this is detected by the tracker 16 and a control signal is sent to the motors 34 and 36 to cause the concave mirror 12 to be rotated in the same direction. Likewise, if the viewer were to move their head up slightly, a control signal would be sent to the servomotors 34 and 36 to cause the concave mirror 12 to be tilted upwards. In this way, the image is moved in a manner that corresponds to movement of the viewer's head, increasing the permissible head movement in the system. This facility also would allow the image to be slaved to

the user's head position such that motion parallax could be introduced. The combination of concave mirror 12, head tracking sensor, feedback control, and kinematic structure of the mirror support frame improves the comfort and ease of use of the system for a user. In particular, by providing the tracking mechanism, the user can move his or her head within reasonable limits while continuing to observe the stereo image. Hence, an enlarged viewing field is provided.

Figure 3 shows an alternative image projection sub-system 42 for use in the auto-stereoscopic system of Figure 1. As before, the projection lens system 46 has a first and a second lens 44 and 46 respectively for directing light into the right and left eyes of the viewer. The images are provided on two orthogonal displays, Display A and Display B. Display A is positioned so that it lies in a plane that is substantially parallel to the optical axis of the first lens 44 of the projection lens system 42. In order to ensure that the image from Display A is projected into the first lens 44, a flat mirror 48 is provided directly facing the display and along the optical axis of the first lens 44. As shown in Figure 4, the mirror is aligned at an angle of 45° relative to the optical axis, but as will be appreciated this could be varied as and when desired. The image of Display A is positioned so that its centre 43 is offset from an optical axis 45 of the first

lens 44. Display B is positioned so that it directly faces the second lens 46 and lies in a plane that is substantially perpendicular to the optical axis 47 of that second lens 46. The image of Display B is positioned so that its centre 51 is offset from the optical axis 47 of the second lens 46.

When the projection system of Figure 3 is used in the display of Figure 1, it is positioned so that the geometric axis 49 of the first and second lenses 44 and 46 respectively is aligned with the optical axis 31 of the concave mirror 12. Light from Display A falls on the flat mirror 48 and is reflected into the first lens 44 of the projection lens system, where it is projected towards the beam splitter. Light from Display B is transmitted directly into the second lens 46, where it is projected towards the beam splitter. Because of the offset positions of Displays A and B and the relative alignments of the geometric axis of the projection system and the optical axis of the concave mirror, the image beams eventually converge on the optical axis of the concave mirror.

Figure 4 shows yet another image projection sub-system 50 that can be used in the system of Figure 1. As before, the optical arrangement includes a projection lens system 52 including first and second lenses 54 and 56 respectively for directing light into the right and left eyes. The image sources, Display C and Display D, are located behind

the lenses 54 and 56. Directly facing Display C is a large, flat surface mirror 58. As shown, this is positioned at an angle of 45° relative to a line perpendicular to Display C. It will be appreciated, however, that this could be varied as desired. This mirror 58 faces inward towards Display C and is sized and positioned so that the entire image on Display C can be projected onto it. Likewise, a similar flat mirror 60 is positioned opposite Display D, with this mirror facing inward towards Display D. These large mirrors 58 and 60 have reflecting surfaces that are symmetrically placed on either side of the projection lens system 52. As shown, the mirrors 58 and 60 are substantially perpendicular, but this is not essential in all implementations. As for the system of Figure 3, the geometric centre of Display C is offset from the optical centre 57 of the first lens 54, and the geometric centre of Display D is offset from the optical centre 59 of the second lens 56, so that the images converge at the image plane.

Also provided in the system of Figure 4 are two smaller flat mirrors 62 and 64 that are positioned on an axis that passes between the first and second lenses 54 and 56 respectively and at 45° relative thereto. It will be appreciated, however, that this specific angle of alignment is not essential and may be varied to meet particular design criteria. Each of the smaller mirrors 62 and 64 is

parallel to the corresponding one of the larger mirrors 58 and 60 respectively and is positioned so that its reflecting surface faces that of the larger mirror. The smaller mirrors 62 and 64 are positioned so as not to obscure any part of the image that is to be projected onto the large mirrors 58 and 60 and at the same time to reflect light transmitted from the large mirrors 58 and 60 into the projection lenses 54 and 56.

When the arrangement of Figure 4 is used in the display of Figure 1, it is positioned so that the geometric axis 61 of the first and second lenses is aligned with the optical axis 31 of the concave mirror 12. Light from each display C and D travels towards the corresponding one of the larger mirrors 58 and 60, where it is reflected onto the corresponding one of the smaller mirrors 62 and 64 and from there into one of the lenses 54 and 56 of the projection lens system 52. These beams are then projected towards the beam splitters, where they are directed towards the concave mirror, so that they eventually converge on the optical axis 31 thereof. As will be appreciated, the degree of magnification of the image in the system of Figure 4 is dependent on the distance of the source displays A and B from the lens assembly and the optical power of that assembly. The focal length of the lenses is selected according to the overall size of the system.

The projection lens system of Figure 4 has been

included in the arrangement of Figure 1. Using a concave mirror having a 560mm aperture with a 400mm focal length and a lens combination consisting of two pairs of lenses of 800mm and 600mm focal length respectively, a highly effective stereoscopic system can be provided.

Figure 5 shows still another image projection sub-system 68 that can be used in the system of Figure 1. This is similar to that of Figure 4, but in this case, rather than having two planar mirrors 62 and 64 and two lenses 54 and 56 to focus the images onto the beam splitter, two concave mirrors 70 and 72 and two beam splitters 74 and 76 are used. An advantage of using concave mirrors in place of lenses is that chromatic aberration can be avoided. Also, in this case, light from the left and right eye screens is orthogonally polarised. In addition, polarising filters are placed over mirrors 70 and 72, each filter being matched to the polarisation of the corresponding image, in order to ensure efficient filtering and reduce ghosting.

More specifically, the system of Figure 5 has two orthogonally polarised image sources E and F that are located in the same plane, but are spaced apart. These image sources are provided in a plane that is perpendicular to the geometric axis of the projection sub-system. Directly above each image source is a plane mirror 78, 80. The reflective surfaces of the plane mirrors 78,80 face

each other, and lie in mutually orthogonal planes, although this is not essential. Between the plane mirrors 78 and 80 are the first and second concave mirrors 70 and 72. Over each of the concave mirrors 70 and 72 is provided a polariser 71 and 73 that is matched to the polarisation of the corresponding image.

Positioned directly above the first and second concave mirrors 70 and 72 are the first and second beam splitters 74 and 76. These beam splitters preferably have a transmission/reflection ratio of 50/50. As shown in Figure 5, the beam splitters are perpendicular to each other, but as will be appreciated, this is not essential for all implementations. As before, the centre of each image is offset relative to the optical axis of the corresponding concave mirror, so that the images beans converge in the image plane.

When the projector of Figure 5 is used in the arrangement of Figure 1, it is positioned so that the geometric axis 82 of the first and second concave mirrors 70 and 72 is aligned with the optical axis 31 of the concave mirror screen 12. Light is directed from the first and second images onto the respective planar mirrors 78 and 80, where it is reflected onto the first and second beam splitters 74 and 76 respectively. Light is then reflected towards the first and second concave mirrors 70 and 72, where it is focused and directed back to the beam splitters

74 and 76. Half of the light reaching each beam splitter is then transmitted through that splitter, and directed towards the concave screen 12. Because of the spacing of the concave mirrors 70 and 72, the images that are ultimately projected towards the screen of Figure 1 are located at the correct inter-ocular spacing. Because the images E and F are orthogonally polarised and the polarisation filters 71 and 73 are matched to these, the projected real image formed on the large concave mirror of Figure 1, i.e. the directional screen, is polarised so that only light from the left image source E enters the left eye and only light from the right image source F enters the right eye. In this way, the exit pupil of the system effectively becomes a virtual pair of polarising glasses.

Figure 6 shows yet another projection system that can be used in the system of Figure 1. This is similar to that of Figure 5, in that it has two orthogonally polarised images G and H, two concave mirrors 70 and 72, two polarising filters 71 and 73, one in front of each of the concave mirrors 70 and 72 and each being matched to the polarisation of the corresponding mirror and two beam splitters 74 and 76, each beam splitter having a transmission/reflection ratio of 50/50. However, in this case, the planar mirrors are omitted and instead the image sources G and H are positioned parallel to the optical axis of the sub-system and located on either side of the beam

splitters 74 and 76. As shown in Figure 6, the images G and H are located at an angle of 45° relative to the beam splitters, but this is not essential and may be varied to meet particular design criteria. The centre of each image G, H is offset relative to the optical axis of the corresponding concave mirror, so that the images beams converge in the image plane.

As before, when the projector of Figure 6 is used in the arrangement of Figure 1, it is positioned so that the geometric axis 82 of the first and second concave mirrors 70 and 72 is aligned with the optical axis 31 of the concave mirror screen 12. Light from the images is directly incident on one or other of the beam splitters 74 or 76. Since the beam splitters have a transmission/reflection ratio of 50/50, half of the light incident on each beam splitter is reflected onto one of the concave mirrors, which focuses the image back onto that beam splitter. Half of the focused light is then transmitted onwards to the beam splitter of Figure 1. As for the arrangement of Figure 5, by using the polarising filters efficient filtering and reduce ghosting can be ensured.

All of the projection systems described with reference to Figures 3 to 6 use two focusing elements, each associated with one of the images. However, in any of these a single focusing element could be used to focus both of the right and left images, as shown in Figure 7(a).

Alternatively, a plurality of such elements could be used, these being stacked along a single optical axis, as shown in Figure 7(b). In either case, a single large exit pupil is formed, through which the observer looks, with the left eye using the left half of the lens and the right eye using the right half of the lens. In the example shown in Figure 7(a), the single focusing element is a lens. Light from each of the right and left images is focused through a right and left part respectively of the lens. Using a single lens, to focus both of the first and second images towards the screen can improve image quality. Further improvements can be gained by ensuring that the optical axis of the lens is aligned with that of the concave mirror, thereby to provide an on-axis system.

Figure 8(a) shows another stereoscopic display in which the invention is embodied. In this case, the projection system is located below the optical axis of the concave mirror, and projects first and second images onto it. The projection system can be any one of those described with reference to Figures 2(b) to 7. The viewer views images on the screen from a position above the optical axis. Hence, in this case, both projection and viewing are off-axis. Figure 8(b) shows the display of Figure 8(a) in a multi-viewer configuration with the image formed on the plane of the mirror. In the case where a real or virtual image is created, the image plane would no

longer reside on the optical axis of the mirror.

Figure 9 shows yet another stereoscopic system. This comprises a concave mirror that provides a viewing surface, and a projection system that includes one or more reflecting surfaces for directing one or more of first and second images onto one or more concave mirrors. In any case, the concave mirrors are adapted to focus the images onto a viewing plane, so that they can be seen by a viewer looking into the concave mirror. As a specific example, a single mirror may be provided for reflecting both images onto a single concave mirror. In this case, the single concave mirror focuses both of the first and second images onto the desired viewing plane. Alternatively, a single mirror may be provided for reflecting both images onto one or other of a first and second concave mirror. As yet a further option, two mirrors may be provided, one for reflecting the first image onto a first concave mirror and one for reflecting the second image onto a second concave mirror. In either of these cases, the first concave mirror is adapted to focus the first image onto a viewing plane and the second concave mirror is adapted to focus the second image onto the viewing plane.

Where a single concave mirror is used, it is positioned so that its optical axis is substantially aligned with the optical axis of the mirror. Where two concave mirrors are used, one for each image, these are

positioned so that the optical mid-point is substantially aligned with the optical axis of the mirror. In either case, the images that are projected are spaced apart by an amount that corresponds substantially to the interocular spacing.

Figure 10 shows an on-axis system that is similar to that of Figure 1, except that the position of the projection lenses is variable. This means that the location of the image plane can be varied, so that the image can be made to appear in front of, on, or behind the plane of the concave mirror. This is a significant improvement over existing systems because it allows the user's eyes to naturally accommodate and converge on the object of interest. Most conventional 3-D displays are limited by the location of the screen. To make the image appear to come out of the screen of such a conventional display, the images are moved to each side of the screen so that the viewer's eyes have to cross slightly in order to view them. Crossing the eyes in this way causes the convergence point to lie out in front of the screen, and so the image appears to lie in this plane. This provides a 3-D effect. However, the focus point is still on the screen and so there is a mismatch between the actual focal plane and the location of the image. This can cause the viewer's eyes to strain and so stimulate headaches and other strain related symptoms. By allowing the image plane to be moved

to a point in front of the screen, or indeed behind the screen, the focal point and the position at which the eyes converge can be more closely matched, so providing a more comfortable viewing experience. Of course, rather than moving the lens or lenses, the display could be provided with a range of interchangeable lenses having different optical powers, each of which could be used in the projection system as and when desired, or a zoom projection assembly could be used.

All of the systems described above allow a single user to view full stereoscopic images that may comprise live or recorded video, cine film, still images, or animated computer graphics and the like. These images may be provided by various means. For example, micro-display technologies could be used to provide the images, such as organic light-emitting displays (OLEDs), liquid crystal on silicon (LCOS) or high temperature poly silicon (HTPS) and digital light processing (DLP), in addition to conventional displays such as CRTs, LCDs, etc.

The system in which the invention is embodied has many advantages over other existing stereoscopic viewers. For example, the disclosed system is glasses free. Also, the full viewing rate of the source display is perceived and this results in a very easy to view stereoscopic image. A further advantage is that it produces full colour images of maximum brilliance and contrast ratio. This is because the

concave mirror creates a highly directional system in that rays from the image are collected and directed straight to the eyes of the user. Furthermore, the system is able to fully utilise the resolution of the source display.

A skilled person will appreciate that variations of the disclosed arrangements are possible without departing from the invention. For example, in Figure 3, the lenses 44 and 46 are shown as being spaced from the top of the mirror 48 by a finite amount d. However, ideally the separation d should be as small as possible and preferably zero. This is true for all of the projection sub-systems described herein. Also, although the display is described as being for use on a desktop, it could be provided in a dedicated viewing booth or on a mobile platform. Alternatively, the display could be miniaturised and provided in a head mountable unit, so that it could be worn. In addition, where specific angles are mentioned, it will be appreciated that these may be varied. Furthermore, the various systems could include means for electronically correcting the image to address key-stoning and distortions brought about by projecting an image onto a curved mirror surface. Accordingly, the above description of the specific embodiment is made by way of example only and not for the purposes of limitation. It will be clear to the skilled person that minor modifications may be made without significant changes to the operation described.

Claims

1. A stereoscopic system comprising an optical element, preferably a concave mirror, that acts as a directional screen, and a focusing element for focusing both of a first image and a second image towards the optical element.

2. A system as claimed in claim 1, wherein optical axes of the optical element and the focusing element are aligned.

3. A system as claimed in claim 1 or claim 2 wherein a deflector, for example a beam splitter, is located on an optical path between the optical element and the projection system for directing light from the projection system towards the optical element.

4. A system as claimed in any of the preceding claims, wherein the focusing element is adapted to focus the first and second images in a viewing plane that is on or in front of or behind the optical element.

5. A system as claimed in any of the preceding claims, wherein a plurality of focusing elements is provided on a common optical axis.

6. A stereoscopic system comprising an optical element,

preferably a concave mirror, that acts as a directional screen; and first and second focusing means for focusing first and second images, the first image being positioned so that its centre is offset from an optical axis of the first focusing means and the second image being positioned so that its centre is offset from the optical axis of the second focusing means.

7. A display as claimed in claim 6, wherein the first and second image sources are positioned so that the first and second image beams eventually converge on the optical axis of the optical element.

8. A system as claimed in claim 6 or claim 7, wherein the first and second focusing means are adapted to focus the first and second images in a viewing plane that is on or in front of or behind the optical element.

9. A system as claimed in claim 6 or claim 7 or claim 8, wherein one or more reflectors are provided for directing the first and second images onto the focusing means.

10. A system as claimed in any one of claims 6 to 9 wherein a beam splitter is located on a beam path between the first and second focusing means and the optical element.

11. A stereoscopic system comprising a movable optical element, preferably a concave mirror, that acts as a directional screen; a projection system for projecting first and second images onto the optical element, the first and second images being provided from first and second image sources; a tracking system for tracking movement of a viewer, and a drive for causing movement of the optical element in response to movement detected by the tracking system.

12. A display as claimed in claim 11, wherein the projection system includes first and second focusing elements.

13. A system as claimed claim 11, wherein the projection system comprises a focusing element, for example a lens, for focusing both of the first and second images onto the screen, preferably wherein a plurality of such focusing elements are provided, each located on a single optical axis.

14. A system as claimed in any one of claims 11 to 13 wherein a beam splitter is located on a beam path between the projection system and the optical element.

15. A stereoscopic display comprising an optical element, preferably a concave mirror, that acts as a directional screen, and a projection system including one or more reflecting surfaces for directing one or more of first and second images onto focusing means, the focusing means being operable to focus the first image and the second image onto a desired viewing plane.

16. A display as claimed in claim 15, wherein the focusing means have an optical axis that is substantially aligned with the optical axis of the optical element.

17. A display as claimed in claim 15 or claim 16, wherein the focusing means comprise a focusing element, for example a lens, for focusing both of the first and second images.

18. A display as claimed in claim 15 or claim 16, wherein the focusing means consist of first and second focusing elements for focusing the first and second images respectively.

19. A display as claimed in claim 18 wherein the first image source is positioned so that its centre is offset from an optical axis of the first focusing means and the second image source is positioned so that its centre is offset from an optical axis of the second focusing means.

20. A display as claimed in any one of claims 15 to 19, wherein the first and second image beams eventually converge on the optical axis of the optical element.

21. A stereoscopic display comprising an optical element, preferably a concave mirror, that acts as a directional screen and generates a plurality of exit pupils for multiple users, the exit pupils being formed by the real image of the focusing elements of a plurality of projection systems including one or more reflecting surfaces for directing one or more of first and second images onto focusing means, the focusing means being operable to focus the first image and the second image onto a desired viewing plane.

22. A display substantially as described hereinbefore with reference to the accompanying drawings and/or as shown in Figure 1, preferably used with any one of the projection systems shown in Figures 2 to 7, or Figure 8 or Figure 9.

1/7

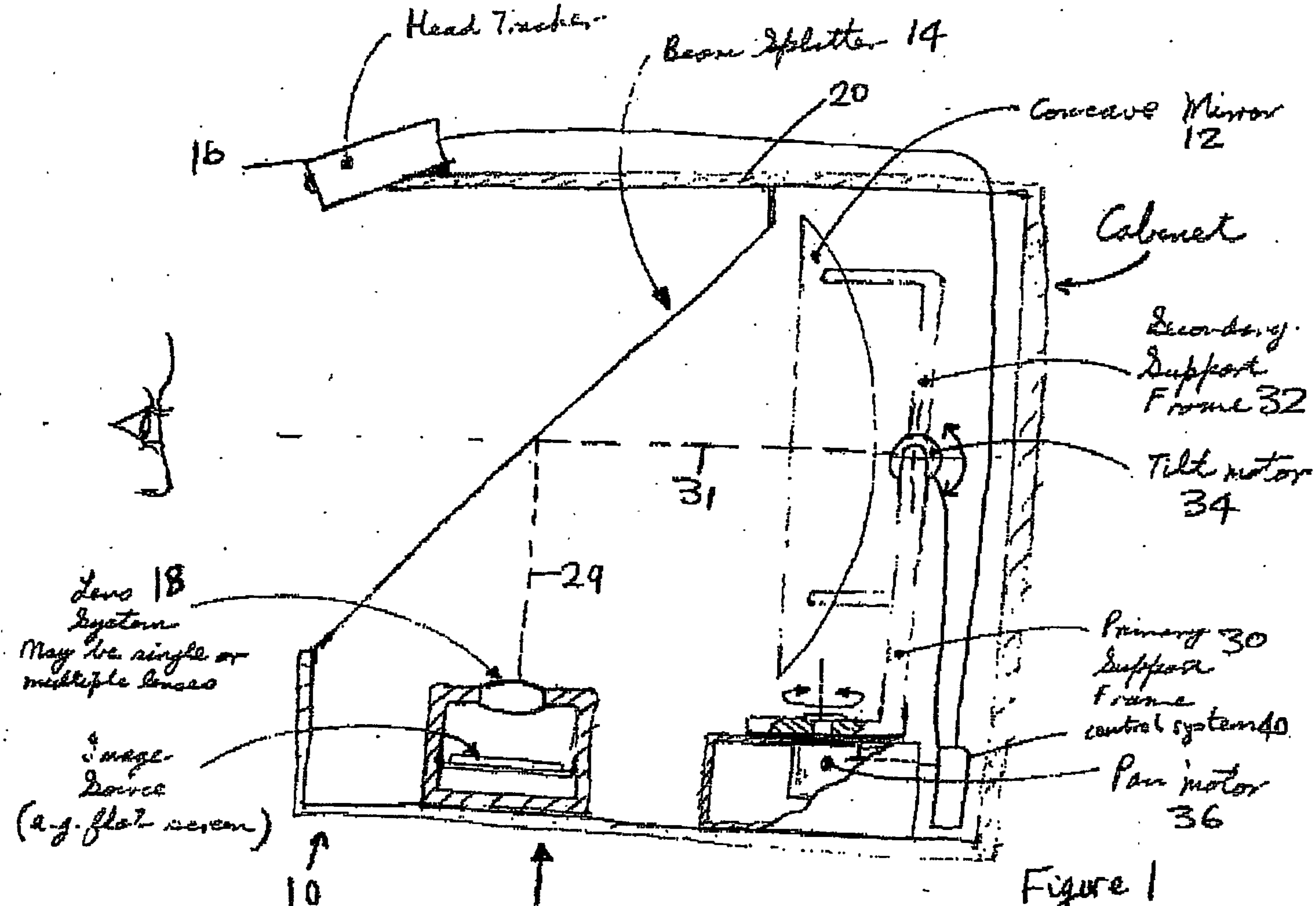

Figure 1

Side View

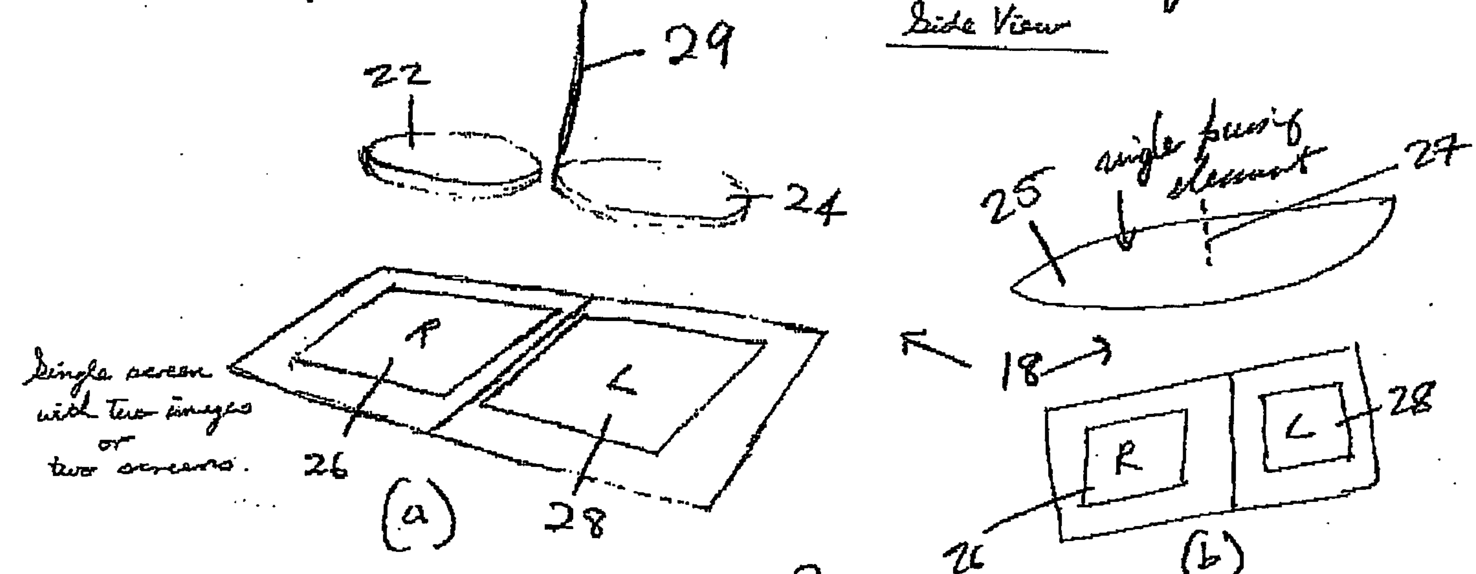

Figure 2

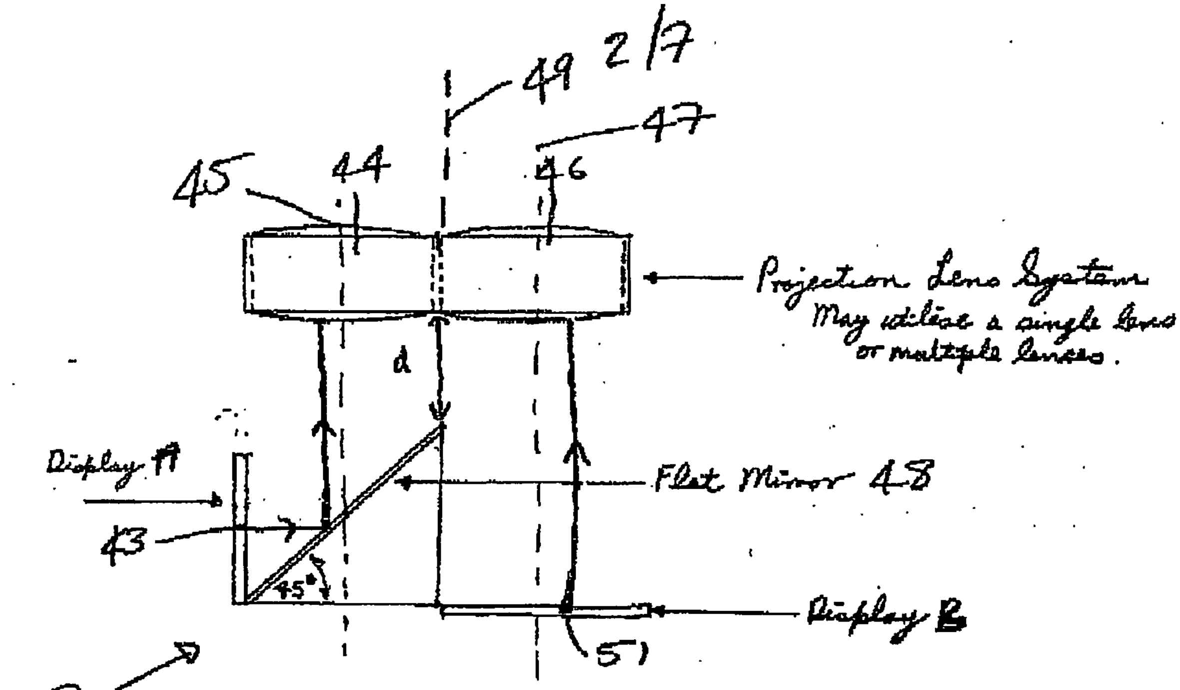

Figure 3

Front View

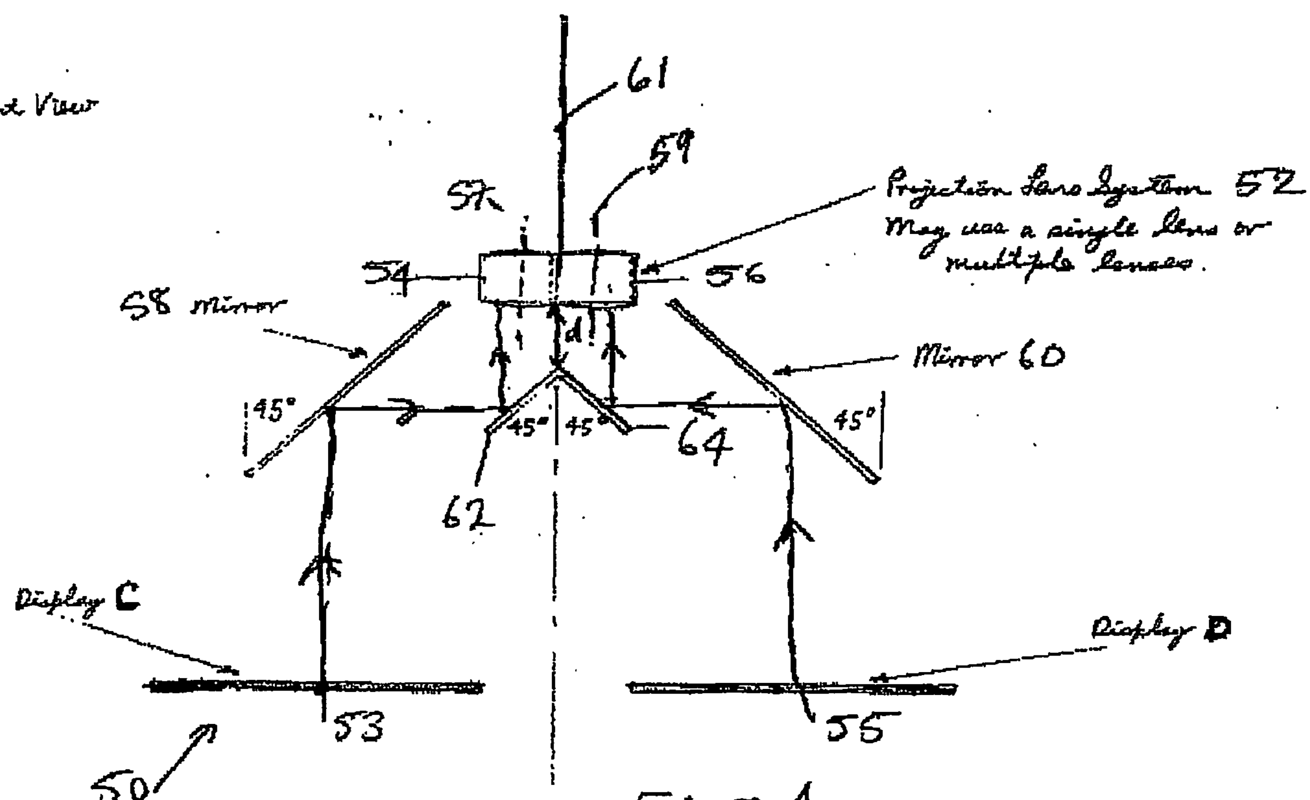

Figure 4

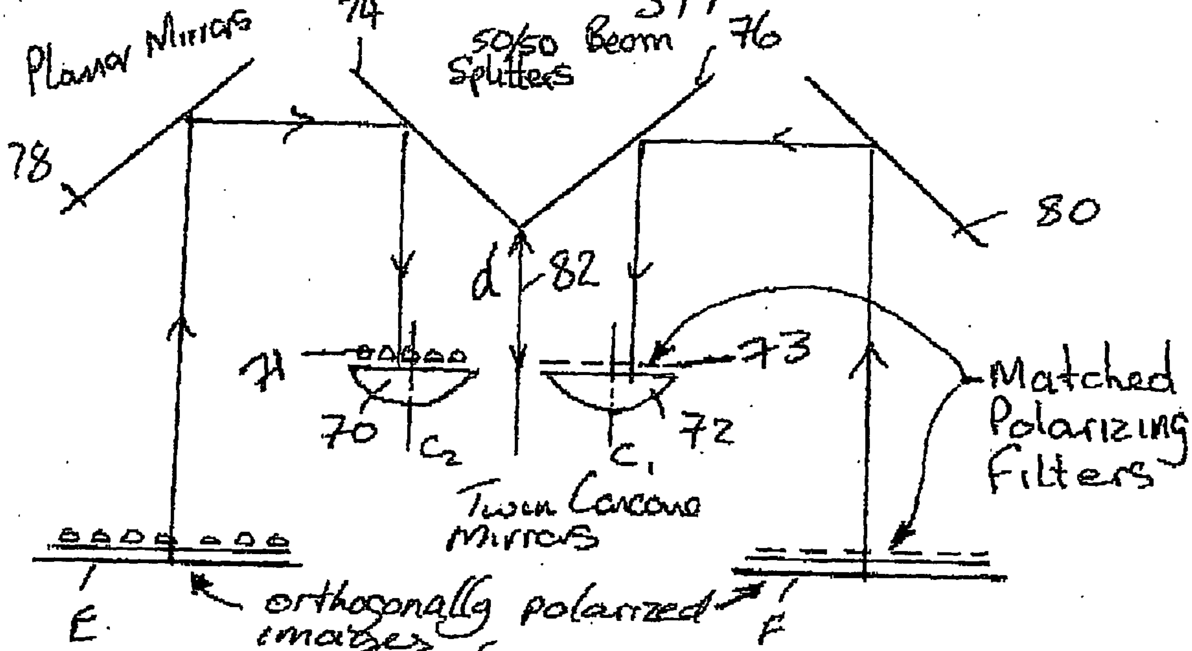

Figure 5

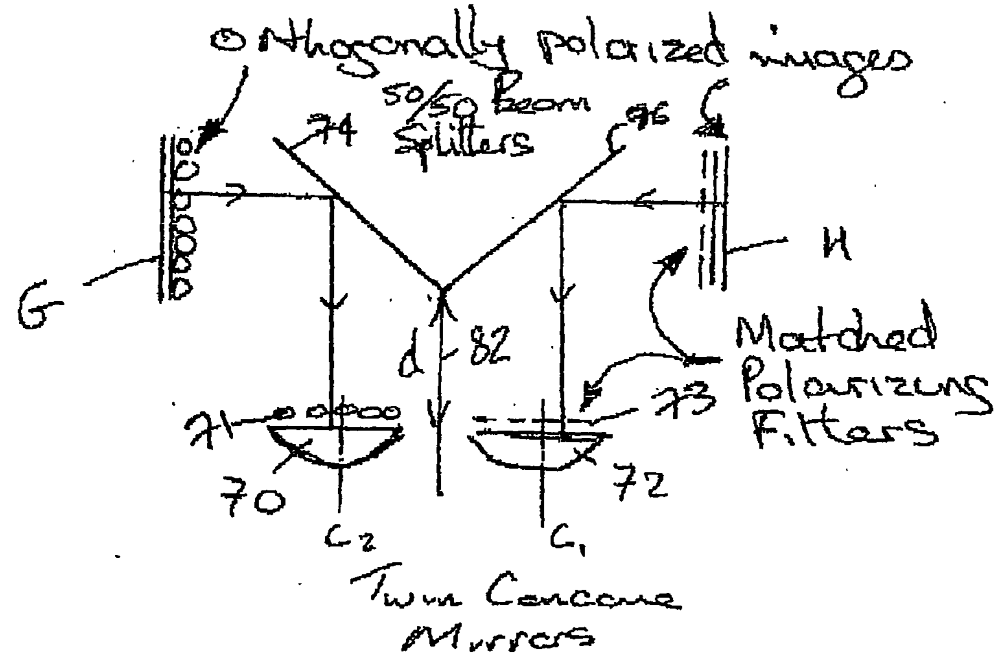

Figure 6

Front View

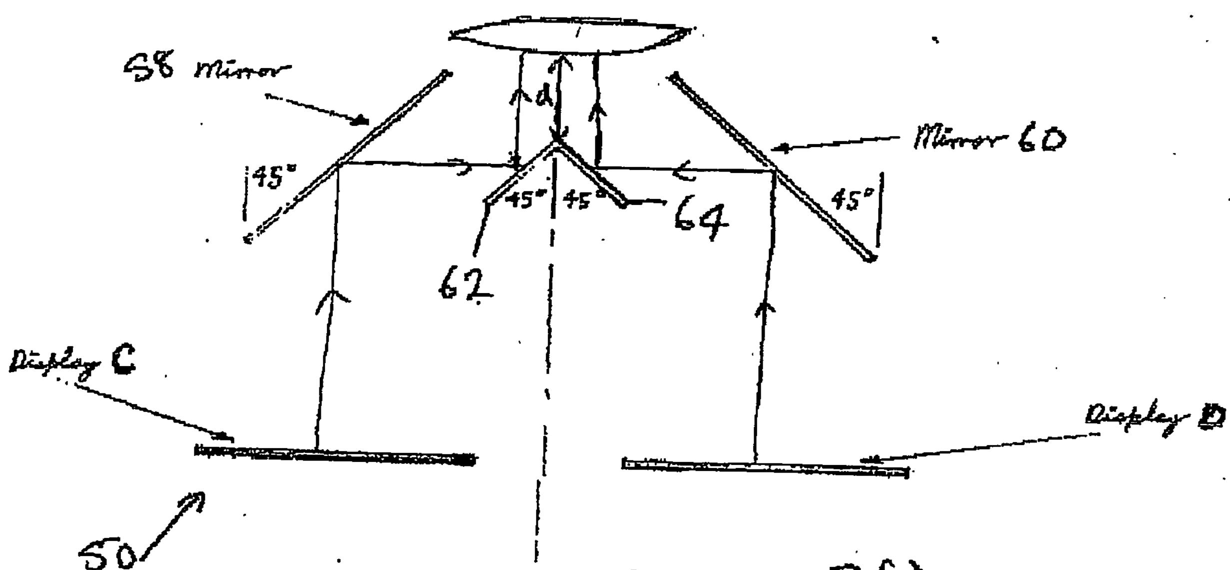

Figure 7(a)

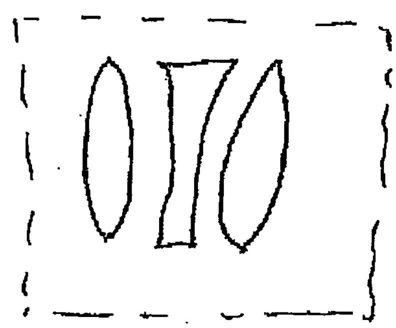

Figure 7(b)

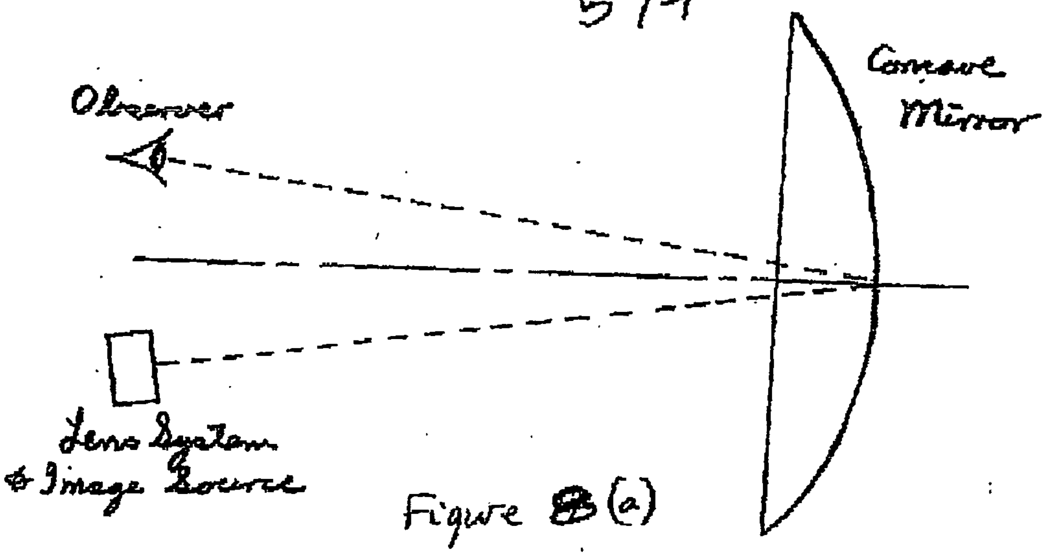

Figure 8(a)

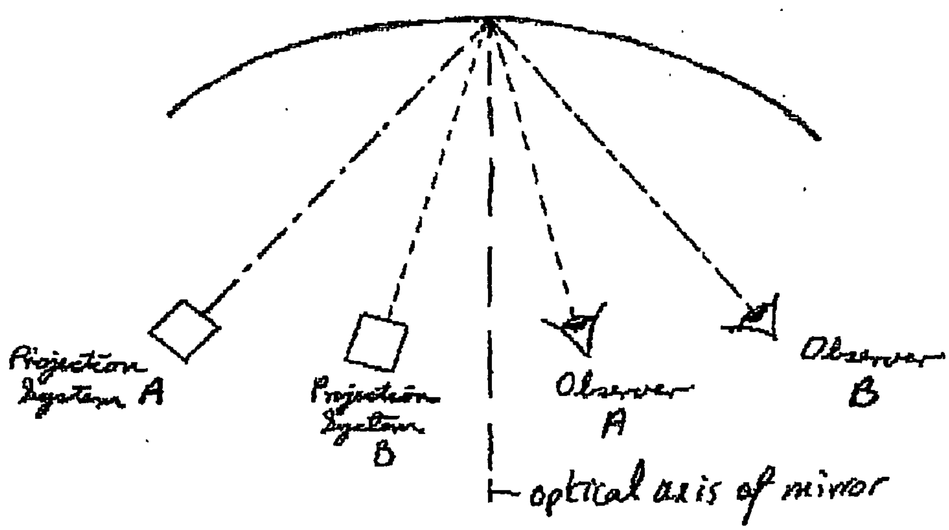

Figure 8(b)

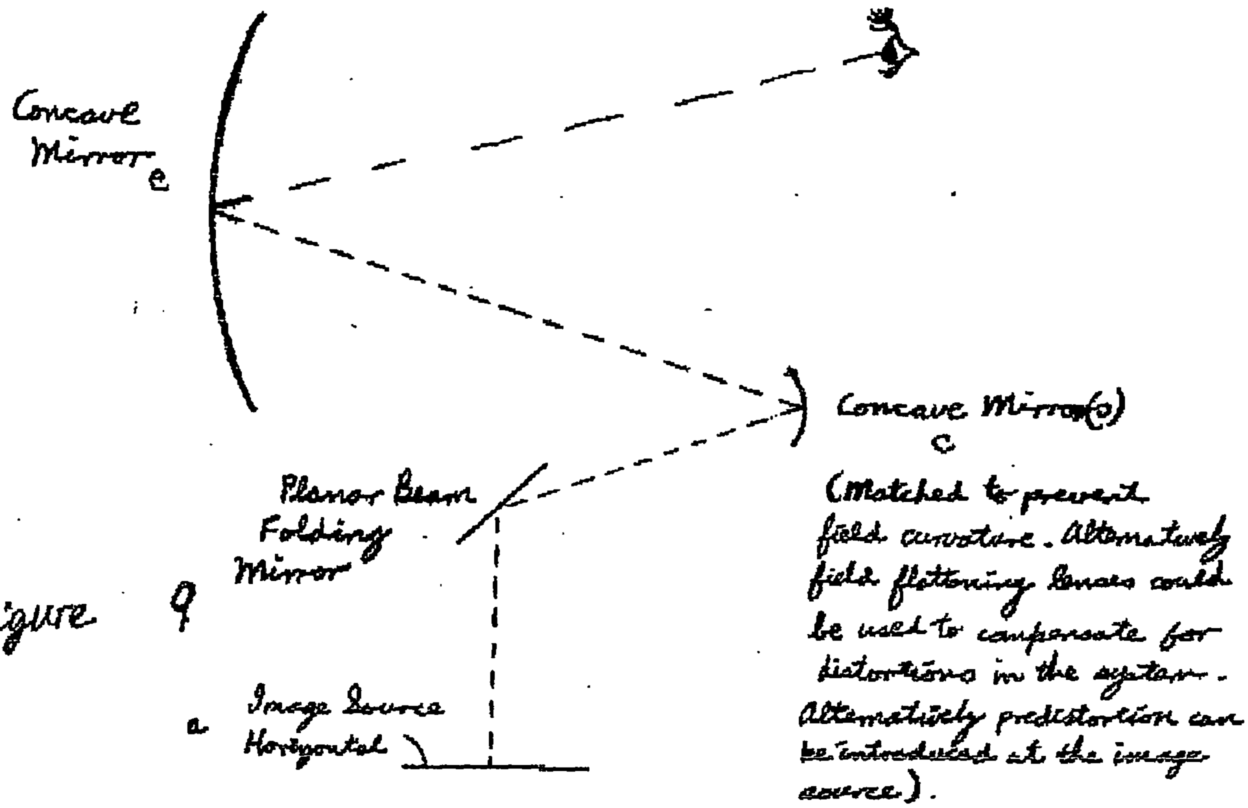
Concave Mirror e
Concave Mirror(s)
c
(Matched to prevent field curvature. Alternatively field flattening lenses could be used to compensate for distortions in the system. Alternatively predistortion can be introduced at the image source).
Planar Beam Folding Mirror
a
Image Source Horizontal

Figure 9

7/7

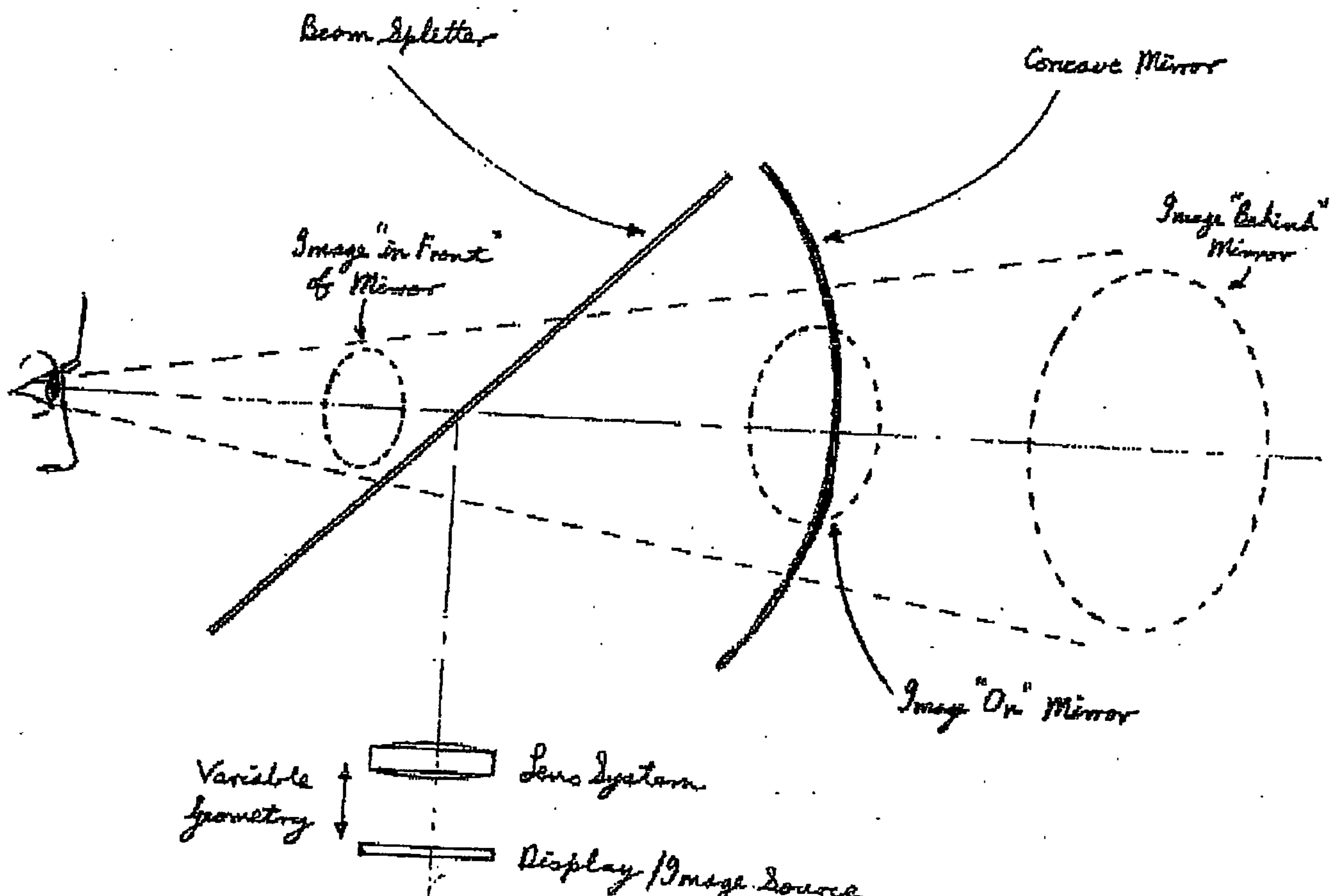
Beam Splitter
Concave Mirror
Image "Behind" Mirror
Image "in Front" of Mirror
Image "On" Mirror
Variable Geometry
Lens System
Display/Image Source

Figure 10